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TELEMETRY CODING STUDY FOR THE INTERNATIONAL MAGNETOSPHERE EXPLORERS—MOTHER/DAUGHTER AND HELIOCENTRIC MISSIONS

VOL. I: SUMMARY OF FINAL REPORT

David E. Cartier
THE Magnavox COMPANY
Advanced Systems Analysis Office
8720 Georgia Avenue
Silver Spring, Maryland 20910

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16. Abstract

This is the final report for the convolutional coding study on the IME Mother-Daughter and Heliocentric spacecraft. It is a compilation of the three previously submitted task reports with supplemental material added to tie the three tasks together. It determines the amount of coding gain needed by the missions, studies and recommends an encoder/decoder system to provide the gain, and finally evaluates the impact of the system on the NASA space network in terms of cost and complexity.

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TABLE OF CONTENTS

TABLE OF CONTENTS (Cont.)

TABLE OF CONTENTS (Cont.)

TABLE OF CONTENTS (Cont.)

LIST OF APPENDICES

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Cont.)

LIST OF ILLUSTRATIONS (Cont.)

LIST OF ILLUSTRATIONS (Cont.)

LIST OF TABLES

LIST OF TABLES (Cont.)

This document is a duplication of the summary section of the final report shown in the title page. The purpose of this duplication is to provide NASA/GSFC with the major results of the contract (NAS5-20386) without burdening those who have no interest in the technical material presented in the final report with the detail that it contains, and yet they may still retain the overall results for action items, planning, or other such uses as is deemed necessary.

References, figures, etc., referred to here are to be found in the complete final report. Also the complete table of contents for Vol. II is used for this volume so that the reader may refer to the titles, sections, etc.

1.0 SUMMARY

The following document is the final report on a study of convolutional coding techniques for the International Magnetosphere Explorers (IME) Mother/Daughter and Heliocentric Missions (IMEMD/IMEH). Previous names for these missions were Interplanetary Monitoring Platform (IMP) KK' and L missions and also NASA/ESRO Mother/Daughter and NASA Heliocentric Missions (NEMD/NH). This report is a consolidation of the three task reports delivered to NASA Goddard Space Flight Center (GSFC) in December 1972, March 1973, and April 1973. All of the technical material found in those reports is duplicated here with explanatory material added.

The tasks imposed by GSFC in the contract statement of work will now be stated to provide a starting point for the rest of the report.

1.1 STATEMENT OF WORK

The Contractor will conduct a study to determine:

- the optimum cost-effective/efficient signal design for the Interplanetary Monitoring Platform, Mother/Daughter and Heliocentric Missions (IMP K-K') compatible with the Spaceflight Tracking and Data Network (STDN).
- the most cost-effective/efficient method(s) for ground handling of the one-half convolutionally coded, downlink telemetry received from these spacecraft. That is, should the data be transmitted from the remote sites to the Project Operations Control Center for decoding, or would noise interference significantly degrade the signal quality and so make it more desirable to decode the data at the remote sites. If the latter is more desirable, what are the most cost-effective augmentations, implementations and techniques for decoding at the remote sites?

1.1.1 TASK REPORT NO. 1

The bit error rate enhancement capability of the planned convolutional coding technique significantly affects the optimum distribution of the downlink signal power between the carrier range code and telemetry. Therefore, the Contractor will determine:

- The bit error rate enhancement that may be expected from the planned coding technique as well as other competitive techniques, for return link telemetry rates anticipated to be no greater than 16,384 information BPS for the IMP dual satellite mission and a maximum data rate of two information KBPS for the downlink telemetry for the IMP heliocentric mission. These rates will be programmable upon command to three lower bit rates which are multiples of 2^N of the maxima.
- Cost-effectiveness trade-offs, in especially those relating to the ground systems.
- Any interfacing problems associated with integrating decoding equipment techniques at the remote ground stations.

These results are to document the performance of the convolutional encoder-decoder in terms of bit error probability or coding gain for 10^{-5} bit error probability.

1.1.2 TASK REPORT NO. 2

Given the results of Task Report No. 1 plus system noise temperatures provided by NASA and using Effective Isotropic Radiated Power of .25 to 5.0 watts, the Contractor will determine the optimum power division among the carrier, ranging signal and telemetry signal for the return link. Parameters to be traded-off are range and range rate accuracy, time and signal power required for acquisition and "lack," and bit error probability.

1.1.3 TASK REPORT NO. 3

- The Contractor will determine the feasibility of decoding and decommutating in real and non-real time at the receiving ground station.
- He will determine whether or not hard-wired decoders are appropriate or whether the decoding can be accomplished at at the ground station with existing computer.

- He will determine the practicality of "tying up" the on-site computers for this purpose.

- He will examine the feasibility of transmitting the telemetry signal, which has been extracted from the return link but which has not been decoded or decommutated, over the NASCOM network via wideband or narrowband lines.

For instance, it may be possible to use wideband channels such as TELPAC A channels for real-time transmission to a central processor for decoding and decommutating, or it may be possible to use conventional voice bandwidth data lines for non-real time transmission to a central processor for decoding and decommutating. In these latter modes, the Contractor will assess the effect of the narrowband or wideband data transmission channels on the net bit error probability at the output of the decoder at the central processor.

- Cost figures will be developed to illustrate whether on-site decoding and decommutating or remote decoding and decommutating are advisable.

- The Contractor will provide definitive answers to the three following questions, which will be documented as a separate chapter of the final report.

    (a) What can be done with the present on-site equipment for the tasks outlined? This is primarily to establish a baseline for comparison purposes.

    (b) What would be the nature of a cost limited modification to accomplish some of the coding advantages?

    (c) What would be an optimum system with state of art approaches including costs and advantages?

1.2 STUDY PLAN

The method that was used to fulfill the work objectives was to perform Task 2 first, Task 1 second, and Task 3 third. The reason for this was that it was felt that a determination of the required coding enhancement (gain) was in order before studying how such enhancement could be attained. After that was accomplished Task 3 could be performed to complete the study.

1.2.1 FIRST TASK SUMMARY

With the above reordering of priorities out of the way, the first task studied (Task 2 in the statement of work) performed a power budget analysis. The purpose was to determine the optimum modulation indices for the ranging and telemetry subcarrier and as a result derive the telemetry coding gain which would be necessary on the downlink.

The power budget is presented on several charts and is discussed on an item by item basis so that each factor of the system is brought into play with its associated impact. As the analysis progresses a series of tradeoffs are made and duly noted. Finally, as a result of all of these compromises, an optimal system is formed for the mission. Optimal here means that set of network elements which assures the greatest quality of data sent from the spacecrafts.

At the end of the analysis a section is presented which gathers, discusses, and explains, in terms of system impact, the conclusions reached in the items previously mentioned. After these conclusions are sufficiently expounded upon, recommendations are set forth which set the trend for the overall system design and its network support.

By way of highlighting the results of the first task, it was found that the coding gain required was 5 dB at 10^{-5} bit error probability; the solar noise factor on the downlink dictates that the minimum halo radius on the Heliocentric mission be at least 60,000 km; the uplink signal-to-noise on the ranging is marginal in the case that the null of the omni receiving antenna is encountered on the Heliocentric mission; all other uplinks can be made to have good margins by efficient use of network facilities; finally, as expected, the Heliocentric mission is marginal on the downlink when near the earth-sun line.

1.2.2 SECOND TASK SUMMARY

A major result of the Task 1 report (1) was that the telemetry system for the IMEMD/H missions required an E_b/N_o of 11.6 dB into the bit synchronizer to achieve an error probability of 10^{-5} without coding. Since only 7.2 dB was available in the IMEH mission when it was close to the sun (this was due to solar noise which degraded the system by about 10 dB) it was determined that at least a 5 dB coding gain should be designed into the system forward error control units.

The second task attacks the problem of achieving the 5 dB gain with a convolutional encoder used in conjunction with the appropriate decoder. It gives the theory of convolutional codes as found in the literature referenced in Section 5. After the theory is presented, the practical aspects of the encoding problem are discussed, and the important and complex subject of decoding is taken up. Three decoders are treated, namely, the Feedback Decoder, the Maximum Likelihood Decoder (also referred to as the Viterbi Decoder), and finally the Sequential Decoder. All of these are commonly used, however, only the last two provide the gain needed by the IMEMD/H missions. The Feedback Decoder is thus only touched upon to the extent necessary to eliminate it from consideration.

The algorithms upon which the two candidate decoders are based are fully developed, and then the practical aspects of implementing the algorithms into decoder hardware are detailed. The culmination of the above is the block diagram design of practical decoders with a discussion of each block.

Finally after the pros and cons of both the Viterbi and the Sequential Decoders have been weighed a recommendation is made to choose the Viterbi. This is based on a tradeoff among performance, complexity, and cost.

1.2.3 THIRD TASK SUMMARY

The third task completes the system study by looking at the the practical aspects of implementing the recommended encoding/decoding system. The limitations of actual hardware together with the costs involved are presented. Five possible configurations of the network (Figure 3.46) are analyzed on a block by block basis, i.e., each part of the system is scrutinized to ascertain whether or not it will prevent the realization of the system or to determine if it is too costly to be practical. After this is done the advantages and disadvantages are listed for each system.

In the conclusions and recommendations the material alluded to above is used to arrive at an optimum system to support the missions. This optimum system consists of the encoder arrived at in task 2 with each support station performing the decoding locally and transmitting the decoded data to Goddard Space Flight Center via the NASA Communications Network (NASCOM).

It will be shown in the text that follows that this system is relatively simple to implement, cost effective, flexible (can be used for future missions with a different bit rate and/or modulation scheme), and provides the experimenter with quality data.